INTERAGENCY REPORT NASA-171

ON THE USE OF SPACE PHOTOGRAPHY FOR IDENTIFYING TRANSPORTATION ROUTES: A SUMMARY OF PROBLEMS

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GEOLOGICAL SURVEY

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ABSTRACT

It has been widely suggested that space photography may be used for updating maps of transportation networks. Proponents of the argument have suggested that color space photographs of the resolution obtained with Hasselblad 80 mm lenses (about 300 feet) contain enough useful information to update the extensions of major U. S. highways. The present study systematically documents for the Dallas-Fort Worth area the potential of such space photography in detecting, and to a lesser degree identifying, the existing road networks. Color separation plates and an enlargement of the color photograph were produced and all visible roads traced onto transparencies for study. In addition, a four county sample area was selected for more detailed analysis in comparing the actual network with those roads detected and other linear elements mistaken for roads. Attempts were made to discover to what degree road width, surface type, topography, land use, and linearity affect road visibility.

Major roads and roads under construction were the most visible while lower class roads and roads in urban areas had the poorest return. Road width and classification were found to be the major determinant in visibility, varying from 100 per cent visible for divided highways to 15 per cent visible of bladed earth roads. In the five county sample area, 4 per cent of the linear elements detected were not roads; but were rather streams and rivers, field borders, pipelines, telephone cables, oil field borders, railroads, lakeshore, waterways, trails to oil rigs, and unknown elements. The sun was at an angle of some 40° above the horizon at the time of the photography, and, as would be anticipated, roads vary in visibility as a function of fore or back-lighting.

In summary, space photographs of this resolution proved to be difficult to use for accurate road delineation. Only super highways in rural areas with the greatest road-width were completely identifiable, the width being about 1/3 that of the resolution cell. Lower class roads were confused with other linear elements or were simply not visible. We would anticipate that, to positively detect and identify all but the smallest of roads, the resolution should be about 50 feet.

INTRODUCTION

The problem of using outdated road and transportation maps or finding accurate new ones has confronted almost everyone from time to time. This is true not only for super highways in the U. S. but also in identifying trails and dirt roads in remote areas that are incorrectly listed or omitted entirely due to outdated or inadequate information. Present methods rely on costly field studies and random if any air photo reconnaissance.

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It has been widely suggested that space photographs may be used for up-dating maps of transportation networks. The proponents of such a view argue that the extremely high-altitude of space photography would permit coverage of large areas with single photos, thus eliminating many inaccuracies in present procedures, while consistently providing current information on the area. New and existing roads could be identified and transportation maps accurately and easily up-dated. The necessary construction of new and expansion of old transportation networks into areas of recent and future urban development could be rationally planned. Existing natural and future man-made obstacles to proposed road construction could be readily foreseen and compensated for, thus eliminating much costly right-of-way purchase at a later date. Presumably, this same identification ability in up-dating maps would be even more valuable in road analysis of remote areas.

In order to use space photography for such purposes it is necessary not only to detect the presence of linear elements (i.e. roads, railroads, pipelines, etc.) but also consistently to identify and discriminate between them. It has been suggested that color space photographs of the resolution obtained with the 80 mm lens employed in the Apollo VI space photography, which lie in the range of 180 to 450 feet (on axis and 20° off axis) with a contrast ratio of 1.6:1, contain enough useful information to update transportation maps showing at least the major highways in the U. S., and that higher resolution photographs, obtained with 150 to 300 mm focal lengths would enable even minor roads to be detected.

The present study, the first of a series, systematically documents for the Dallas-Fort Worth area the potentials and problems of Apollo VI color space photography in the detection and identification of existing road networks. This area was selected for examination because of the apparent number of visible roads and the variety of landscapes, soils and land uses available. Figure 1 is a 3 times reproduction of the space photograph showing the area covered, while Figure 2 gives both the Interstate and U. S. Highways, with major towns and cities. We have found in this study that to be consistently detected a road normally should have a width (road plus shoulder width) of equal to or greater than one-fourth of the resolution cell at a contrast ratio of 1.6 to 1. For the Dallas area this means that only roads (actually roads plus shoulder width) no less than 70 feet wide would be fully, and unambiguously, detected.

As the road width decreases other elements enter into a resolution cell resulting either in misidentification of roads with other linear elements, or a failure to detect roads. Consequently, for certain identification we estimate at this time that the resolution of a film should be of the order of the narrowest road which one desires to identify. With resolutions of 50 to 100 feet one should be able to detect paved, two lane highways, and a fifteen foot resolution should enable detection even of narrow dirt roads in most cases, provided sufficient background contrast is maintained. Further studies are planned for the fall of 1969 using photographs with resolutions of 10 feet to 100 feet to document the validity of this hypothesis.

CAMERA AND FILM DATA[1]

The Apollo VI space photograph shown in Figure 1, is one of a stereo triplet obtained April 13, 1968, at 8:43 a.m. local sun time, from an altitude of 128 statute miles. The camera employed was a 70 mm J. A. Maurer Model 200-G sequence camera. Each frame (41° field-of-view) was taken 8.64 seconds apart with 65 per cent overlap at 1/500 second and f 5.6. Spacecraft stabilization was such that the photograph has less than one-half degree tip in the direction of flight and one-third degree tilt across track. The lens used was a f 2.8 Kodak Ektar of 76 mm focal length without a filter. In order to reduce the high atmospheric luminance from short wavelength Rayleigh scattering a sharp cutting Wratten 2E haze filter was used which cut with 6.5 per cent transmission at 420 nanometers, 59 per cent at 430 nm, 80 per cent at 440 nm, and 90 per cent at 480 nm. Beyond 500 nm it is virtually flat in its response at 91 per cent transmission to 720 nm. The film used was Kodak type SO-121, a high resolution, high contrast, aerial color positive.

Since sufficient quantities of flight emulsion were not available prior to shipment of the camera to the launch site no resolution testing was done using the flight film and flight lens. However the manufacturer's lens test at f 2.8, 1/1000 sec with Plus-X (type 3401) film gave the following average of radial and tangential resolutions with a high contrast target: 0°, 71 line pairs/mm; 5°, 70; 10°, 65.5; 15°, 46; 20°, 35.5; and 25°, 13. Areal weighted average resolution was 45 line pairs/mm. It has not proved possible for us to test this lens with SO-121 film but, from performance tests with other lenses and films we believe this lens-film combination would be

[1] In the preparation of this section we have drawn heavily from an updated, unsigned manuscript "Camera System and Calibration," Apollo AS-502 (Apollo VI) by the Instrumentation and Electronic Systems Division, Manned Spacecraft Center, Houston, Texas. Quotations labelled 'camera system' are from this document.

likely to have a performance at a contrast ratio of 1.6:1 (a common ratio between roads and background in this area, as well as being a standard value) of the order of 50 line pairs at 0° (nadir) and 5°; 45 at 10°; 30 at 15°, 20 at 20°, and 10 or less at 25°. These resolutions give equivalent ground resolutions on the 70 mm film, with a mean scale of 1:2,800,000 of 180 feet at 0° and 5°, 200 at 10°, 300 at 15°, 450 at 20°, and 900 at 25°. A rough areal weighted average resolution would be 30 line pairs per mm, equivalent to 300 feet with a 1.6:1 contrast ratio.

The photographs were taken through a hatch window inclined at such an angle to the camera that the light rays reaching the camera ranged from "near normal at the corners in the direction of flight to approximately 10° at the center of the leading edge. The angles of incidence increase toward the trailing edge when they become greater than 50 degrees" (Camera Systems). The significance of this is that using a refractive index of 1.5442 for quartz, the maximum polarization of light in the plane of the surface occurs at 57°4'. In addition the Apollo window consists of a series of plates, thus multiplying polarization effects as the rays pass from surface to surface, first through an optical grade quartz heat shield, then multilayer blue-red reflection coatings, and then through 2 panes of Corning #1723 aluminosillacate glass, themselves coated with reflection reducing layers. Thus the light rays reaching the film range from slightly polarized at the edges in the direction of flight to completely polarized, or nearly so, at the trailing edge and corners (Camera Systems).

The combined effect of differences in resolution across the lens, some lens vignetting, (the side hatch window frame does not cause vignetting) and (in some cases) the difference in the degree of polarization of the light reaching the film from the leading to the trailing edge will be considerable in influencing the detection of narrow linear elements such as roads. In addition since the solar angle was about 39° with the sun relatively at azimuth 106°, tall trees and buildings cast shadows of twice their height. There should therefore be some differences in detection in the fore-lit (azimuth 286°) and back-lit (azimuth 106°) direction depending in part on road direction and on the presence of trees or buildings lining the roads.

STUDY PROCEDURES

Six times enlargements of the color photograph and the red, green, and blue color separation plates were produced and all linear elements thought to be roads were traced onto transparencies for study.[2,3] Those roads visible on each of the color separation plates and the color photograph were compiled separately and combined into the two accompanying maps. Figure 3 depicts those roads detected when the separation plates and the color photo were combined. Figure 5 was created by placing an overlay of the visible roads on an orthochromatic print of the space photo.

In studying the roads, the enlargements were viewed with various magnification on a Richards light table with different intensities of back- and fore-lighting. The color transparency was also projected, viewed under a stereoscope (3X, 8X, 16X) with the adjacent photographs to obtain binocular reinforcement. Only that part relating to the paper positive enlargements is reported here as the other work is not yet complete.

To achieve meaningful results the investigator must always make a certain number of arbitrary decisions which serve as guidelines for the project. It is necessary for the reader to know of the decisions made here in order to view the conclusions from the proper perspective.

Linear elements (roads) were separated into three categories of visibility (high, medium, and low). It was felt that three was the optimum number in order to obtain the most distinct and separate classification and thus the least confusion and overlap. In looking at a visible line on the photograph the decision to identify it as a road or another linear element was the investigator's also. A road often disappeared while going through an urban area and at single spots in rural areas. The decision to infer its route or delete it in such cases was also the choice of the observer. Analysis of a sample region of the Dallas-Fort Worth Metropolitan area proved that the number of visible roads was too minimal (22%) to be considered. Therefore an arbitrary line was drawn around the cities and they were excluded from the study. In smaller cities and towns, attempts were made to detect only highways; never city streets. Finally, sample areas had to be selected for more detailed investigation. Four counties, each in a different area of the photograph and with different terrain, land use, and soil color were chosen as representative of the photograph as a whole (Figure 2).

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[2] A 6X magnification was used so that viewing with an additional 3X Richards Binocular viewer would be adequate for detection of roads, while the 6X magnification provided an adequate scale for plotting.

[3] The color separations were made using standard black and white masking techniques.

The roads detected in the four county sample area on the color photograph and separation plates were transferred to 1:250,000 scale county maps. These maps, obtained from the Texas Highway Department, proved invaluable in the study. All existing roads, except for minor private trails were represented as well as pipelines, cables, and railroads. The road network on the maps was updated as of January 1, 1967 within 16 months of the Apollo VI space photography.

Detailed analysis discovered that many false alarms, lines incorrectly identified as roads, had been detected; although they were linear in nature they were not roads but were later discovered to be other natural and cultural features. Topographic maps and air photo mosaics of the area were used to identify these false alarms. The percentage of actual roads visible on the color photograph and/or color separation plates varied with each of the counties, from 66 per cent for Collin County to 37 per cent for Hood-Somervell Counties. With this result in mind we have analyzed a number of factors which affect road identification. Before proceeding to this analysis, it is necessary first to discuss the types of roads present in the area, for the general character of the roads is an important factor influencing their detection.

TEXAS HIGHWAY DEPARTMENT ROAD CLASSIFICATION

The Texas Highway Department distinguishes six major classes of roads in the study area as follows:

1. Divided Roadways: These are concrete or asphalt super-highways at least two lanes abreast or more on each side of a divider. Commonly, they also have service roads paralleling them, especially near major cities such as the Dallas-Fort Worth complex. The road width is approximately 46 feet, shoulder width an additional 24 feet and right-of-way a further 230 feet. Such a road is illustrated in Figure 6-1.

2. Paved Roadways: These are two lane concrete or asphalt highways with either gravel or asphalt shoulders. The road width averages 24 feet, the shoulders add 16 to 20 feet and the right-of-way occupies an additional 56 feet. The portion of the right-of-way that is not road surface usually consists of well-kept green grass with occasional small trees and shrubs. At times the right-of-way is cluttered by trees, brush, or commercial advertising but this is almost always along older roads. Naturally in urban areas the right-of-way is much narrower, consisting only of the road and occasionally the shoulder (Figure 6-2).

3. Bituminous Surfaced Roadways: These two lane roads are usually 20 feet wide but occasionally, for some state highways, widen to 26 feet. The shoulders consist of gravel or asphalt and usually total 6 to 8 feet wide, yet many of the minor roads of this type have no shoulders. The amount of right-of-way depends on its role as a major traffic artery. Minor farm-to-market roads may have only 60 feet (including road and shoulder widths), while state highways usually have 120 feet. Naturally the upkeep of the right-of-way is relative to its use (Figure 6-3).

4. Metal Surfaced Roadways: These two lane roads are of two types, those using yellow gravel and those using white gravel, depending on the area. The roads themselves are only 18 feet wide and have no shoulders. The right-of-way width varies from 40-69 feet (including road surface) but is usually the former. The right-of-way itself is brushy and weedy unless the farmer has used it to extend his fields up to the road (Figure 6-4).

5. Graded and Drained Roadways: These roads consist of natural earth with very slight chat or gravel cover to aid trafficability in wet weather. The roads are 16 feet wide with no shoulder. In addition their slopes have been graded to promote drainage and water run-off. Right-of-way consists of 50 feet including road surface but is weedy and brushy. The farmer usually utilizes it to expand his acreage, and crop capacity, (Figure 6-5).

6. Dirt Roads: Dirt roads are supposed to be 16 feet wide and even have some gravel on them. In practice they are often one lane or narrow two lane paths with ruts and their surface consists of dirt native to the area. There are no shoulders and the 40 foot right-of-way seldom fully exists. More often the road is surrounded by weeds, overhanging trees and brush, or abuts fields and fences (Figure 6-6).

FACTORS INFLUENCING ROAD DETECTION AND IDENTIFICATION

In addition to the camera window, lens and film limitations, touched upon earlier, there are certain environmental factors that cannot easily be altered. However, they must be understood and taken into consideration when analyzing road networks from space. Road width, right-of-way, road type, topography and water bodies, linearity, land use, and sun angle are the environmental elements found to have the greatest effect on road detectability.

Road Width and Right-of-Way

As Table 1 indicates, the widest roads (road surface plus shoulder) were most easily seen and most often detected. One hundred percent of the divided highways were detected (Figure 7-7) but the percent visible drops rapidly as the road width declines until an average of only 15 per cent of the narrowest roads were visible. Field work led to the conclusion that shoulder width and material play a vital role in visibility. Those roads having a wide shoulder made of a material, e.g. caliche gravel, that contrasted vividly with the adjacent land were more easily seen from the air than those without shoulders (Figure 7-8). Problems of false alarms and loss of visibility were pronounced in all classes of roads except broad, divided highways; but even they were less visible in urban areas (Figure 7-9). The width of the right-of-way and its use also influenced road visibility. The most visible roads were those with wide right-of-ways containing few trees or brush (Figure 7-10). It was found that most weedy ditches had the same reflectivity as well kept grass ditches at this time of year, but the presence of trees and shrubs significantly reduced this reflectivity. Thus, ditches with trees and shrubs have a lower contrast ratio with adjacent cultivated land.

Road Type

The road type or paving surface of each road was obtained from the legend of each county map and the percent of each type visible was computed. Table 2 illustrates the relation of road surface type to road detection. Eighty per cent of the paved roads and sixty-five per cent of the bituminous surfaced roads were detected, but only thirty-eight per cent of the metal surface (gravel), eighteen per cent of the graded and drained roads, and fifteen per cent of the earth roads were visible. In two counties, Collin and Johnson, no bladed earth roads could be detected. The figure for Hood and Somervell Counties, 43 per cent, may be somewhat misleading since there are only 34 miles of bladed earth road in the county and thus a small mileage detected resulted in a very large percentage.

From these figures one is led to believe that the road surface is most important to detectability. However, as will be shown in a later section the contrast ratios between road surfaces and background land use are actually higher for gravel roads than for paved surfaces. Since the lower three types of roads did not have road shoulders their poor visibility is probably due to decreased width except in the case of small weathered dirt roads. The reflectivity of these dirt roads was found to be near that of bare ground and significantly less than either gravel or paved surfaces. Field observations indicated that roads under construction were always more visible than an old road of the same class (Figure 7-11). All of the observed construction sites consisted of broad areas denuded of vegetation utilizing yellow podzolic soils for fill. This resulted in a much higher reflectivity than the black loam soils encountered on small dirt roads in the area. In other words, the broader the surface in use, whether in construction or by surface material (excluding black dirt) the easier it was to detect.

Topography and Water Bodies

Confusion of roads with topographical and hydrographical features was one of the major problems and causes of confusion in this study. Comparison of the space photograph with 1:250,000 scale topographic maps of the area, air-photo mosaics, and aerial oblique photographs showed that the rougher the terrain the weaker the visibility and the greater the error. As a road passed through hill cuts, into valleys or around hills its visibility almost always lessened and at times the road disappeared (Figure 7-12).

In Hood and Somervell Counties, which are the most dissected, 62 per cent of the roads were not visible and 7 per cent of those lines detected were in error. By contrast in the gentler landscape of Collin County only 44 per cent of the roads were not detected and only 4 per cent of the lines were incorrectly identified. Yet, since topography accounts for 48 per cent of the incorrectly identified roads, it is obviously a problem even in the best areas of the photograph.

Lakes, streams and rivers compounded the topographic problems and were sometimes mistaken for barely visible roads in each of the sample counties as Table 3 indicates.

Fifty-eight miles of rivers and streams, 7.2 miles of waterways, and 4 miles of lakeshore were incorrectly identified as low visibility roads. This represented 35 per cent of the total error in the sample area. The four miles of lakeshore were east of Dallas in the dark blue portion of the color space photo. Since many linear elements ran adjacent and up to the lakes on all parts of the photo it was assumed they were roads to lake cottages and beaches and indicated as such. In this instance, however, the high return was due to the lakeshore itself and a newly constructed dam.

Figure 8-13 illustrates the high reflective quality of a lakeshore when compared to the roads in the area. Actual roads crossing, running parallel to, or up to water bodies were found from observation and field work to be more difficult to detect, this being especially true of roads in the barely visible class.

Linearity

Barely visible roads on the photograph which followed a grid or rectangular pattern were always more easily seen than a sinuous road of the same type, as is shown in Figure 8-14. Linearity did not affect those roads in the upper two categories (very visible, visible) as much, but even they lost some of their reflective quality if they began to weave. From observation and ground studies it was concluded that narrower metal, dirt, graded, and bituminous roads (i.e. roads other than those paved or divided) were always more difficult to detect if they were sinuous. Much had to be inferred in tracing their routes. This fact also led to confusion with streams, as stated above, since both had similar meandering characteristics. For example, Hood and Somervell Counties consist of rough terrain with meandering streams. Consequently, 412 miles were incorrectly identified due either to being not visible or linear elements other than roads; this amounted to 69 per cent error! By contrast Collin County, having a rectangular grid system, had 22 per cent less error (see Table 4).

However, sinuous elements were not the sole cause of error. In many cases linearity itself was a major contributor to false alarms. These elements, classified as barely visible roads, consisted of 39 miles of field borders, 28 miles of pipeline, 10 miles of telephone cable, and 13 miles of railroad. Together these linear elements composed almost 46 per cent of the total false alarm error (Table 3). The ease of confusion of these elements with roads is illustrated by Figure 8-14, 8-15, 8-16, and 8-18.

Land Use

Study and observation of the photographs and the sample area in particular indicated that land use also presented problems in road detectability. Urban areas and clusters of dwellings always decreased the visibility of the road in question. Those roads classed as visible or barely visible in rural areas often disappeared upon entering even a small village and their route had to be inferred or discontinued until it reached the other side of the town. In general the larger the urban area the more difficult it became to detect a road. As previously stated, the visibility in the Dallas-Fort Worth Metropolitan area was so minimal that it was excluded from the study completely. Given the same color photograph, those roads in blue areas, which as a result of field work were usually found to be wheat or bare plowed ground, were always more visible than roads in the rust or brown colored areas — stubble, pasture, or bare ground (Figure 8-17 and 8-18). Rural areas, depending on land use, enhanced or decreased road visibility. Observation in the field and oblique photographs found those roads in areas such as Collin County, where fields were more rectangular, cultivated, and had crop growth, contrasted very readily with the surrounding land, but in Wise and Hood-Somervell Counties the many oil rigs, pasture, grassland, and the dissected landscape hindered road detection. The effect of background land use on road detectability will be discussed in terms of reflectivity in a later section.

Sun Angle

The creation of fore and back lighting due to the position of the sun in relation to the camera contributed to the already numerous variables and problems in road detectability. In the series of color space photographs covering the Dallas-Fort Worth area the sun lay at 39° above the horizon at an azimuth 106°. From three over-lapping color space photographs of Collin County, Texas (Table 5) it was documented that road detectability depended on the county's position on the photograph in relation to the sun. In each of the three photographs approximately the same percentage, 65 per cent, of the roads were visible, but they were different roads. Consequently, one is confronted with the problem or difficulty of studying over-lapping photographs of the area taken from various angles. However, when this was done the percentage of visible roads jumped to 80 per cent.

A low sun angle can decrease the detectability of gravel roads when they appear in the backlighted portion of the photograph. This effect makes the relationship between sun angle and camera look direction extremely important. At low sun angles the small pebbles present on gravel surfaces cast shadows and significantly reduce the road reflectivity. In this case with a sun angle of 39° the shadows are approximately the same size as the gravel. Thus, for many gravel roads a moderate percentage of the surface will be in shadow.

It should be noted that, for this study, the county road map showing actual roads was used when locating visible roads on the photograph to eliminate false alarms. This a priori knowledge accounts for the higher visible percentage than the figures given in Table 4.

Detectability: contrast ratio of roads and background

In order to establish the relative importance of the following factors in road detectability, measurements of contrast ratios between road surfaces and backgrounds were made in the field during March-April, 1969, following the Apollo IX flights.

a. road surface
b. actual road width
c. total right-of-way width
d. adjacent land use

The measurements were made using a Minolta Auto-Spot 1° light meter. In order to obtain multi-spectral measurements selected filters were placed in the optical path of the meter. Large samples of measurements were taken and then computer analysis reduced the data to means and normalized standard deviations (Table 6). In order to standardize the measurements and eliminate the effects of atmospheric conditions each group of measurements was accompanied by a calibration measurement from a standard 18 per cent reflection gray card. In Table 6 the broad band values are in foot-Lamberts. The blue, green, and red values are in arbitrary but related units since they have been normalized to yield equal values for the standard gray card according to the following procedure.

$i = 1 \Rightarrow$ Blue
$i = 2 \Rightarrow$ Green
$i = 3 \Rightarrow$ Red

V_i = value of reading for a category for color i

G_i = value of reading for gray card for color i

N_i = normalized value for category for color i

$$N_i = V_i \frac{\sum_{j=1}^{3} G_j}{G_i}$$

The road surfaces were divided into two categories as follows:

divided roadways paved surface roadways bituminous surface roadways	Paved Roads
metal surface roadways graded and drained roadways	Gravel Roads

This was done because except in the case of new unused concrete roads there was no significant difference between the measurements made on the three classes of road surfaces referred to as paved roads. Three factors account for this lack of differentiation. First, after a concrete road has been used there is a deposition of tire rubber and exhaust fumes on the surface which reduces its reflectivity (Figure 6-1). Second, most asphalt roads in the area have light chat embedded in the surface which raises the reflectivity (Figure 6-3), and third, road shoulders are of the same light colored chat for all highways. The two classes of road surfaces referred to as gravel roads also appear identical. Although no statistical tests were performed to substantiate this grouping the data arrays for different surfaces were scanned and they appeared so similar no attempt was made to differentiate them. The normalized standard deviations in Table 6 are no higher for roads than for the other categories thus justifying this grouping. There is no category for dirt roads because of the lack of a large available sample and because in the few roads which were measured the results did not differ significantly from the bare ground land use category.

The rural land use categories listed in Table 6 were chosen because they were those most often encountered adjacent to the roads being studied. The condition of road ditches varied widely from mown grass to unkempt weeds (Figures 6-1, 6-3, 6-4, and 6-5) however, the normalized standard deviation of measurements from ditches was as low as or lower than most other categories. This indicates that regardless of the condition or texture of the road ditch the reflectivity was about the same. For these reasons all road ditches were treated as a single category. It was noted while in the field that at that particular time of year both well kept grass and weedy ditches contained a combination of dead yellow vegetation and a new growth of green vegetation. This would account for the similarity in reflectivity. However if the ditches contained any significant number of trees or shrubs the reflectivity was severely reduced. A small number of readings were

Quality Control and Resolution

This study has created an awareness of the extreme importance of quality control when reproducing space photography. Preliminary mapping was done on color enlargements made from a duplicate transparency (generation unknown). The transparency was a poor reproduction of the original and had extremely high contrast with saturated colors. The marginal quality of the reproduction made it impossible to distinguish land use types with subtle hue differences but nearly equal intensities such as wheat and bare ground. On the transparency and color print these two categories could not be distinguished. The first transparency was accepted as being representative of the qualityavailable. Newtransparencies recently made available have now revealed the lack of quality control in producing the first transparency.

The color separations used in this study were also made from the poor duplicate transparency. As previously stated the red spectral region should produce a higher contrast image than the blue or green. If, in addition, the image reproduction was excessively contrasty the resulting red separation would exhibit such a degradation of tonal quality that it would be of little use for mapping. This could account for the preference in this study of the blue and green separations over the red separation in detecting roads.

Preliminary studies of the multispectral photographs from Apollo IX (March 1969) confirm that the red spectral region is indeed better than the green for detecting roads. Thus quality control should be of prime concern when duplicating space photographs.

Space photographs with resolutions on the order of 300 feet are adequate for detecting super highway systems with assurance. However, in order to map narrower roads a higher resolution will be required. A small number of space photographs taken with a 250 mm lens and having a resolution of approximately 100 feet are available. These show great promise for mapping a more complete road network. Figure 9 is an approximately 8 times enlargement of a portion of such a photo taken from Gemini VII (December 1965) showing Titusville and vicinity near Cape Kennedy, Florida. For comparison an 8 times enlargement of a portion of the Dallas-Fort Worth photo is also given in Figure 9. A comparison of the two portions of Figure 9 shows the marked improvement in detectability of narrow roads on the higher resolution image.

CONCLUSIONS

Although the color space photograph of Dallas-Fort Worth appears to have good resolution and return at first appearance, closer observation and analysis proved that it contains many different but inter-connected problems and is insufficient for study of a complete transportation network. The paved highways and "super expressways" of America are easily visible due to their wide surface width. As the class of road lessons, so does its width, hence visibility, until the point is reached that only a minute portion of gravel and dirt roads are detected...and they are barely visible. Topography, water bodies, linearity, land use, sun angle, and quality control all present additional problems in the possibility of road identification. As a result color space photography of this resolution is useful only in detecting major roadways in rural areas. If further detail or analysis is attempted other linear elements or false alarms become incorporated into the supposed network.

Color space photography possesses great potential in the study of transportation networks, but many of the problems must first be eliminated. Future research will include photographs of a higher resolution with the expectation that minor roads and complete road networks can be consistently detected and identified. Also a series of photographs of the study area should be taken from several angles due to the previously mentioned effect of the sun.

Further studies are now under way to document the consistency of color space photography in road detection. Nine separate photographs of the Dallas-Fort Worth area taken from Apollo IX will be used to analyze the road detection consistency of photographs with 300 foot resolution. The photo enlargement of the Titusville-Cape Kennedy, Florida area will also be studied to substantiate the increased capacity of higher resolution photography in road detection. In addition, studies of photographs with resolutions varying from 10 feet to 100 feet are to be conducted later this fall to determine the capabilities and limitations of such systems in detecting transportation networks from space.

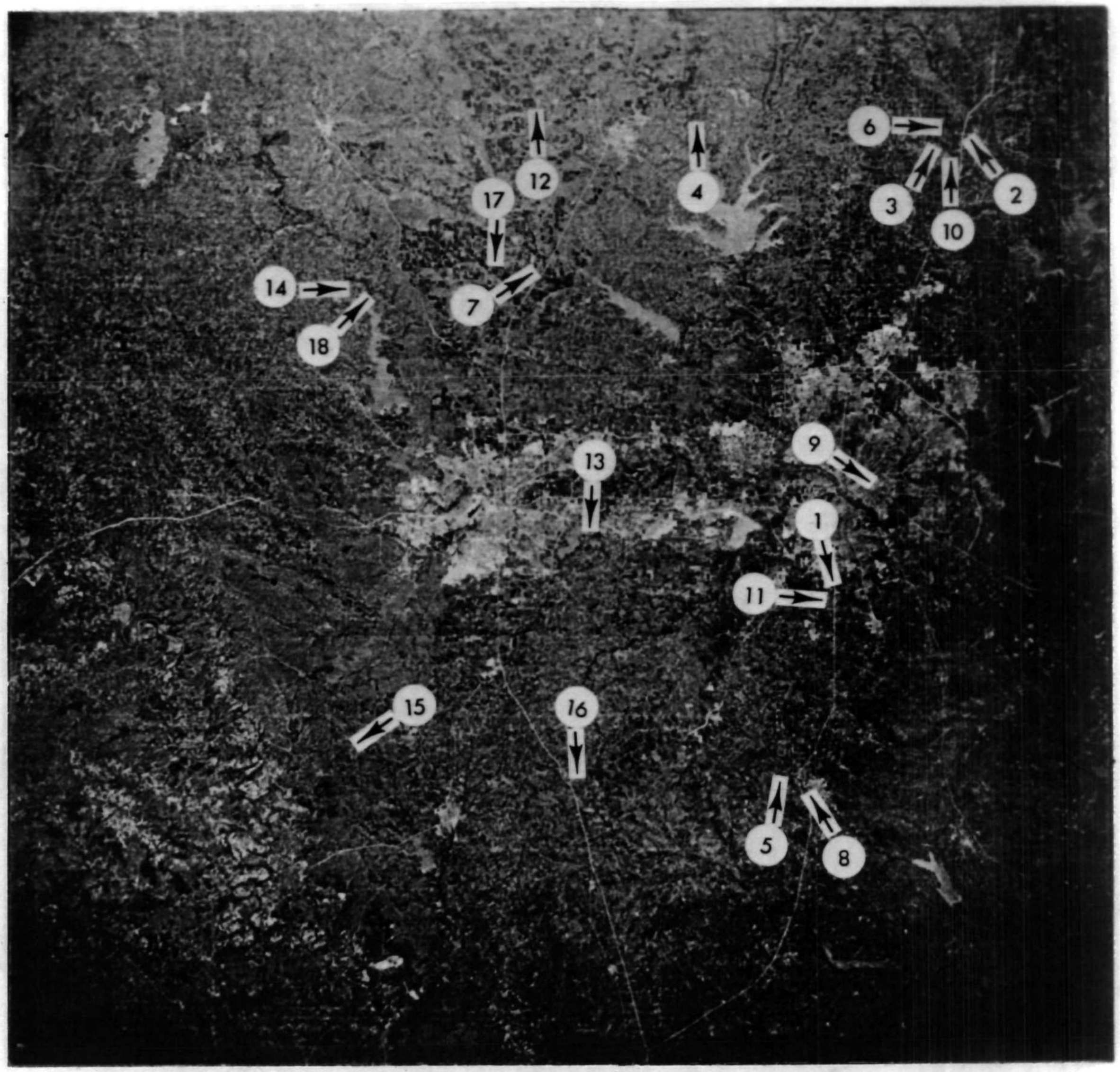


Figure 1. A 3X black-and-white enlargement made from Apollo VI Ektachrome photo, April 13, 1968. The aerial oblique photos and ground photos in the paper were taken during the first week in April, 1969 and are keyed to this area. The oblique photos provide some measure of the road network interpretations made from the space photograph. The numbers on the photograph correspond to the illustrations in Figures 6, 7, and 8.

DALLAS-FORT WORTH AREA COVERED BY APOLLO VI SPACE PHOTOGRAPH, APRIL 13, 1968

Base: Sectional Aeronautical Chart

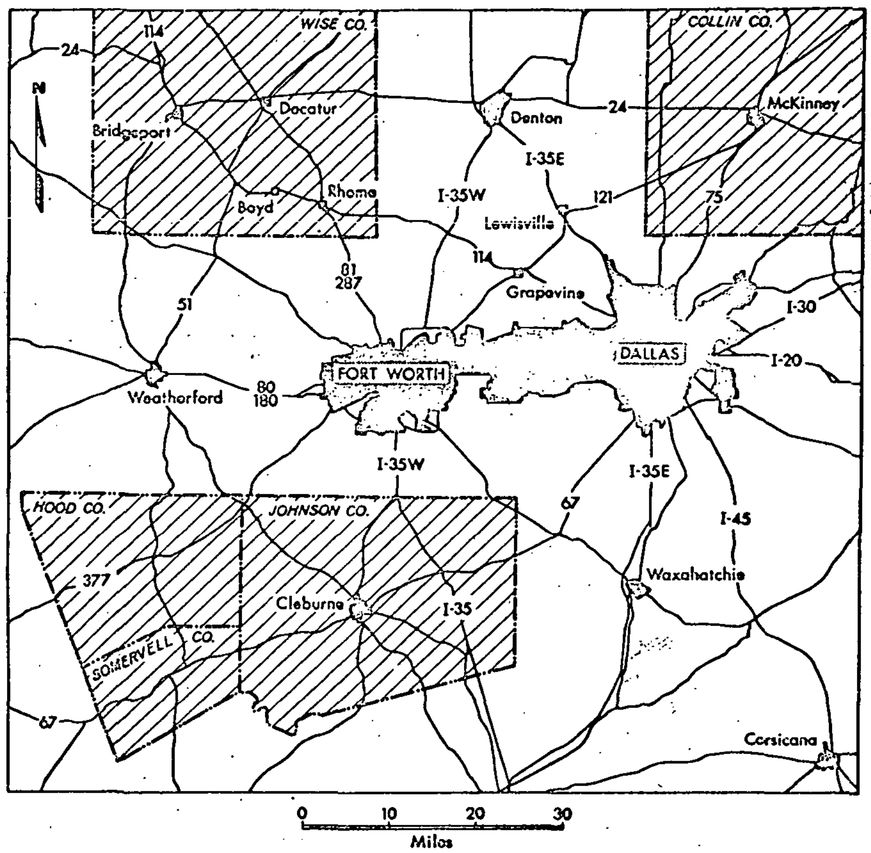
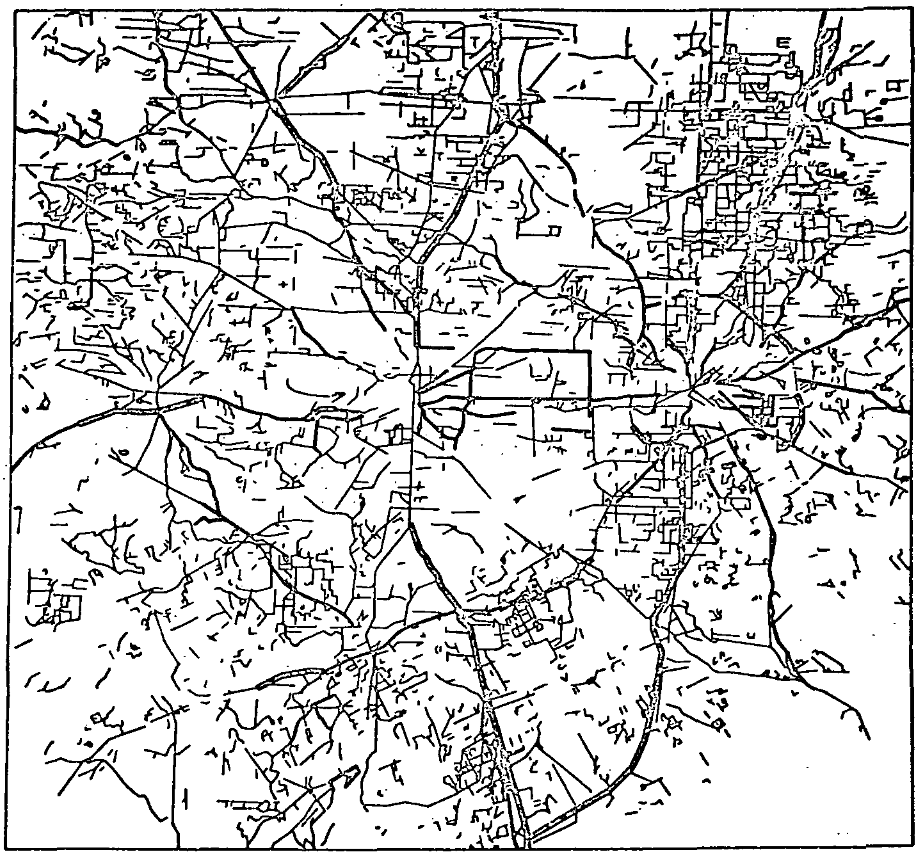


Figure 2. This map depicts the area covered by the space photograph. The Dallas-Fort Worth Metropolitan area, excluded from the study, as well as a four county sample area are shown by shading. By comparing the map with the photo it can be seen that each sample county is in a different land use area, and that even some of the major roads are not visible.

ROADS* DETECTED ON A SPACE PHOTOGRAPH: Dallas-Fort Worth Area, Texas



DETECTABILITY ON APOLLO VI PHOTOGRAPH, APRIL 13, 1968

High —— Medium —— Low

*Roads include linear features mistaken for roads.

Figure 3. Linear elements detected on Apollo 6 color space photo of the Dallas-Fort Worth area. Three categories of visibility are shown.

ROADS* DETECTED ON A SPACE PHOTOGRAPH AND COLOR SEPARATION PLATES:

Dallas-Fort Worth Area, Texas

—— COLOR APOLLO VI PHOTOGRAPH, APRIL 13, 1968

—— ADDITIONAL ELEMENTS ON SEPARATION PLATES

*Roads include linear features mistaken for roads.

Figure 4. Roads detected on a space photograph and color separation plates of the Dallas-Fort Worth area, Texas.

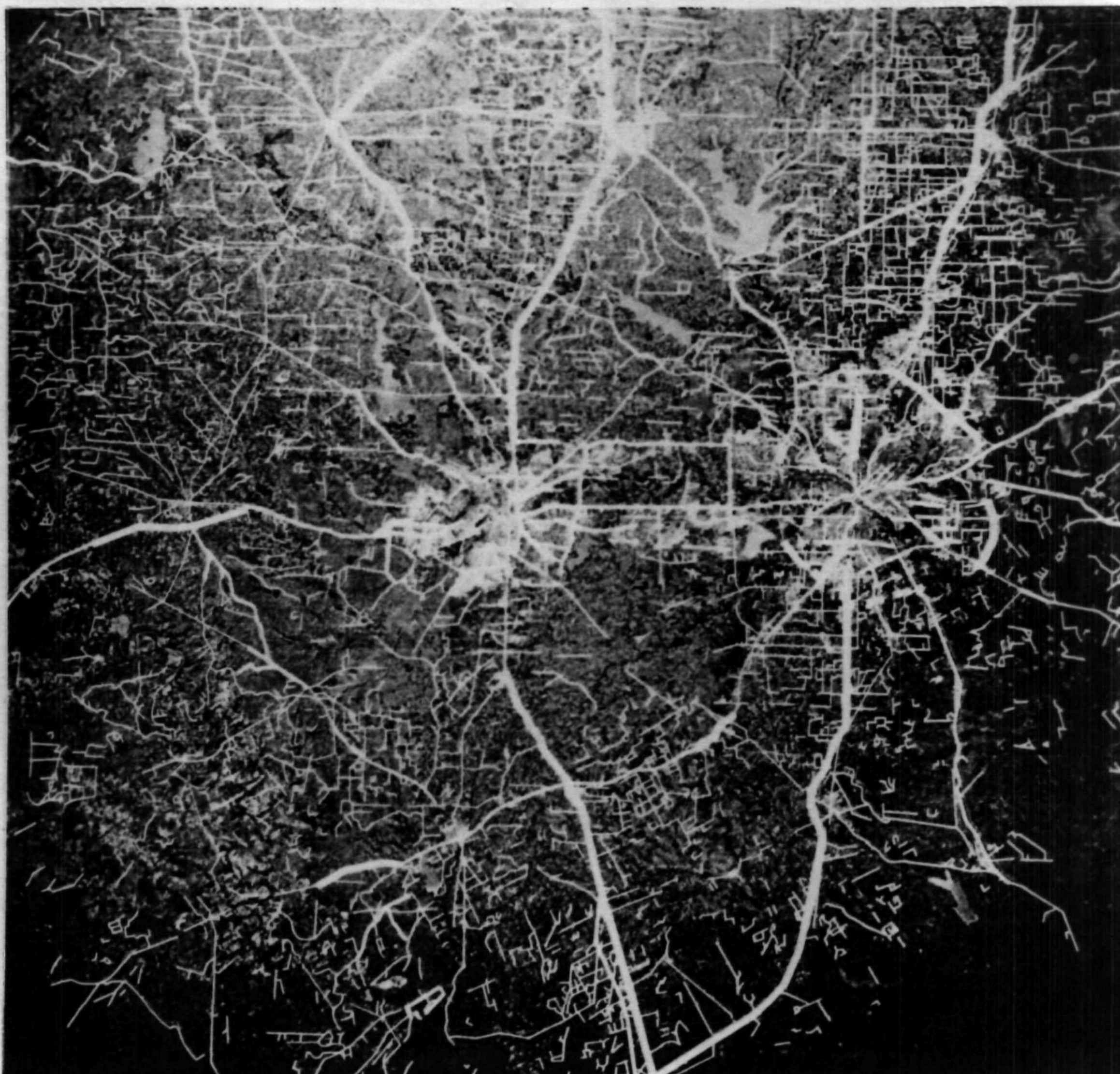
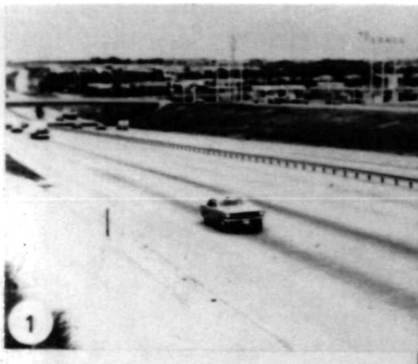


Figure 5. Visible roads overprinted on an orthochromatic print of the Dallas-Fort Worth space photo.



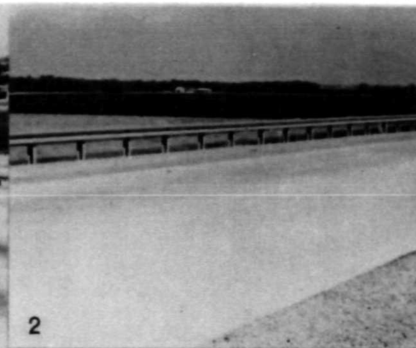


Figure 6-1. Interstate 35, a divided highway, going south out of Dallas to Waxahatchie, is an eight lane road with two lane access roads on either side. With such a wide concrete surface it is easy to see why it has high reflectivity and can easily be seen in rural areas from the space photograph. In urban areas, such as this however, the visibility is reduced due to other paved surfaces and a lack of contrast with its adjacent land.

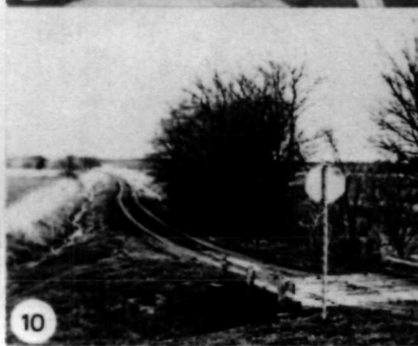
Figure 6-2. U. S. 75, just west of McKinney, is a paved concrete highway. Recently constructed, the concrete has not been darkened by tire wear, exhaust fumes or weathering. As a result it appears almost white against a dark, cultivated background. Paved roadways are 25 feet wide and with their shoulders are 37 feet wide.

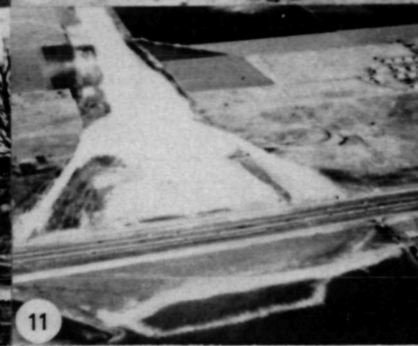
Figure 6-3. Farm-to-Market Road 2478 west of McKinney is an asphalt road with little or no shoulder. Although the asphalt itself is black a significant amount of chat is embedded in the surface. This gives the road a net high reflectivity. Although such roads are visible in many areas the consistency of detection with space photography of this resolution depends on the adjacent land use. Bituminous surfaced roads are 20 feet wide and normally have an additional 8 feet of shoulder width.

Figure 6-4. Metal surfaced roads (gravel) such as this one near Denton seldom have shoulders and are usually only 19 feet wide. As a result their visibility from space is highly variable. When gravel is used against plowed ground it is naturally more visible than when next to brown pasture. Despite their pronounced contrast with green wheat and bare soil such roads as a group were too narrow to be consistently detected.

Figure 6-5. Graded and drained roads such as this one west of Waxahatchie consist of native dirt and scattered gravel, built-up and sloped by a road maintainer. Being narrower than gravel roads (16 feet wide) visibility from space is happenstance. Here, there is plowed ground on one side but pasture and stubble on the other. As a result the road may appear as only a field border from space.

Figure 6-6. Bladed earth roads such as this one near McKinney were seldom detected. Besides being very narrow (fifteen feet or less and lacking shoulders), the right-of-way is obviously almost nil and is not clear or mown. Trees, shadows, and weeds hinder detection.





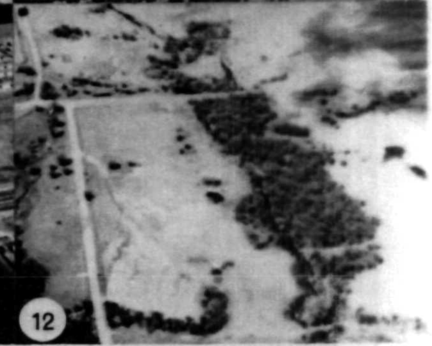


Figure 7-7. Interstate 35, a four-lane divided highway near Justin, is much more visible here than State Highway 114 (E-W) which intersects it in the right center of the photo. The four-lane road has a much wider right-of-way in addition to access roads which accent the total road surface. Road width plays an important part in detectability from space since the elements being detected are near or below the system resolution limits.

Figure 7-8. The white gravel shoulders of this concrete highway U.S. 287 west of Waxahatchie add to the road surface and aid in visibility. The well-kept right-of-way with either bare ground or green grass also adds contrast for the road with respect to certain classes of background land use.

Figure 7-9. This low altitude oblique of Dallas shows the effect of the urban maze on roads entering and within the city itself. Notice how the road at the left top of the photo disappears as it enters the suburban areas. From altitudes of 110 miles it was impossible to detect the Interstate I-20 shown here, let alone the many side streets.

Figure 7-10. This example near McKinney illustrates the importance of right-of-way in road detection. What right-of-way the dirt road does have is ill-kept and contains over-hanging trees, water and brush; from high altitudes the road appears as only a field border.

Figure 7-11. Notice how much more visible is Interstate 635, under construction, than Interstate 35 which runs from left to right across the lower portion of the photo. The broad, graded dirt surface of I-635 provides a much wider and more sharply contrasted surface to the adjacent fields than does the completed paved and grassed I-35. It is understandable why roads under construction were always the most visible on the space photography.

Figure 7-12. The linear, grid system, roads in this photograph near Krum are readily visible, but the others are not. From the lower left corner of the photo a road follows the line of trees to the right, crosses the stream and extends to the right side. Unless the road is known to be there it is almost entirely invisible. The road that extends from the upper left center to the lower right corner of the photo is equally difficult to detect. This terrain could hardly be classified as rugged. The difficulties of detecting roads in a dissected landscape can be imagined.

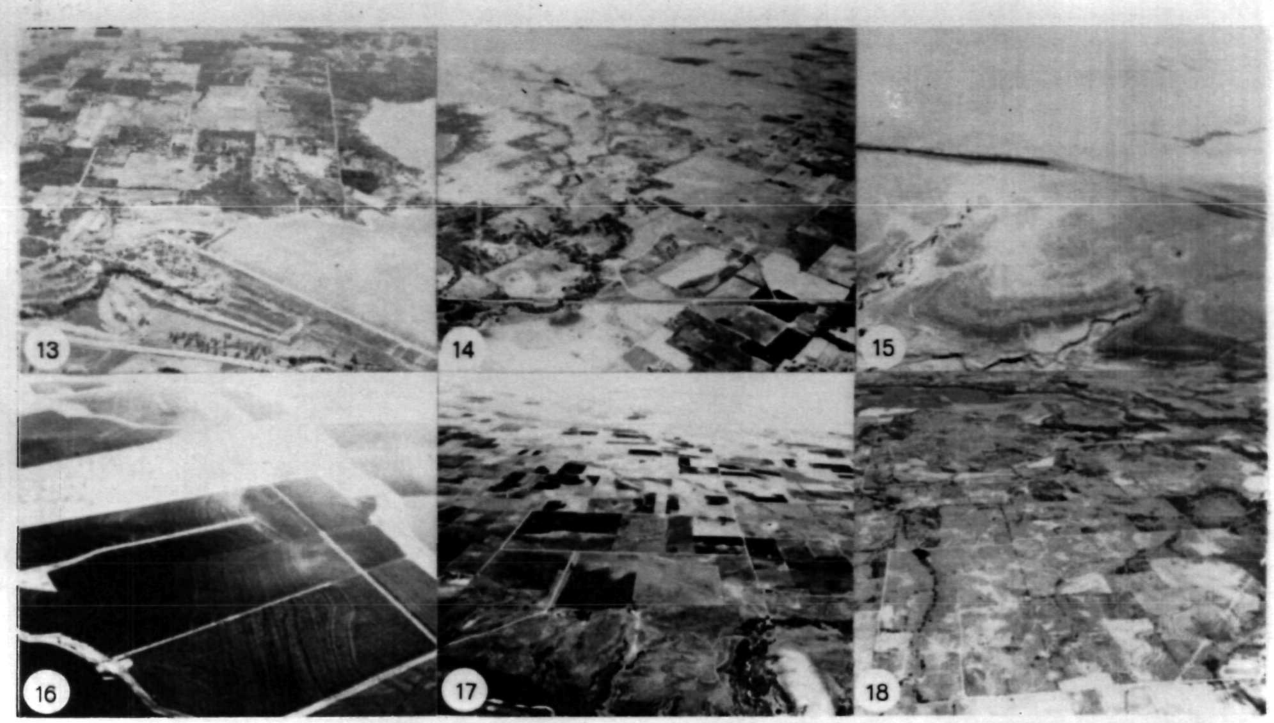


Figure 8-13. The shore of Lake Arlington near Fort Worth could easily be mistaken for a road from a high altitude. It is difficult to define where roads to lakeside cottages and beaches end and the shore itself begins. Close observation is needed even at this altitude to determine if a road crosses the dam or if it turns left to follow the lakeshore.

Figure 8-14. The road which meanders up the middle of the photo near Boyd from bottom to top and the one which runs from left to right across the center are much less visible than the rectangular road system on the right side of the photo. Yet, even linearity poses its problems in road detection; the straight line across the bottom of the photograph is a railroad.

Figure 8-15. The railroad track and train in this photo near Cresson are easily visible but could still be mistaken for a road. The roads which run from the lower left to center and from left center to center top of the photo are far less visible. Again we are presented with the problem: Is this linear element a road?

Figure 8-16. It is possible by close observation of this aerial oblique area to determine which of these lines are field borders and which are roads, but it requires a trained eye. From space platform altitudes such borders could be and were mistaken for roads; whether a better resolution could solve this problem or not has yet to be determined.

Figure 8-17. and 18 Figure 8-17 shows the rectangular field and road pattern of a portion of Denton County while Figure 8-18 illustrates the dissected, cross-hatch field and road systems of Wise County. In the photo of Denton County the roads are easily visible and detected with the aid of field borders; Wise County roads are more difficult to differentiate from other linear elements (such as the pipeline running across the lower right corner of the photo). The land use in Figure 8-17 is mostly wheat and other crops contained in regular field patterns and roads can more readily be defined. The pasture and extensive areas of fallow ground in Wise County tend to blend in with the roads and thus hinder road detection.

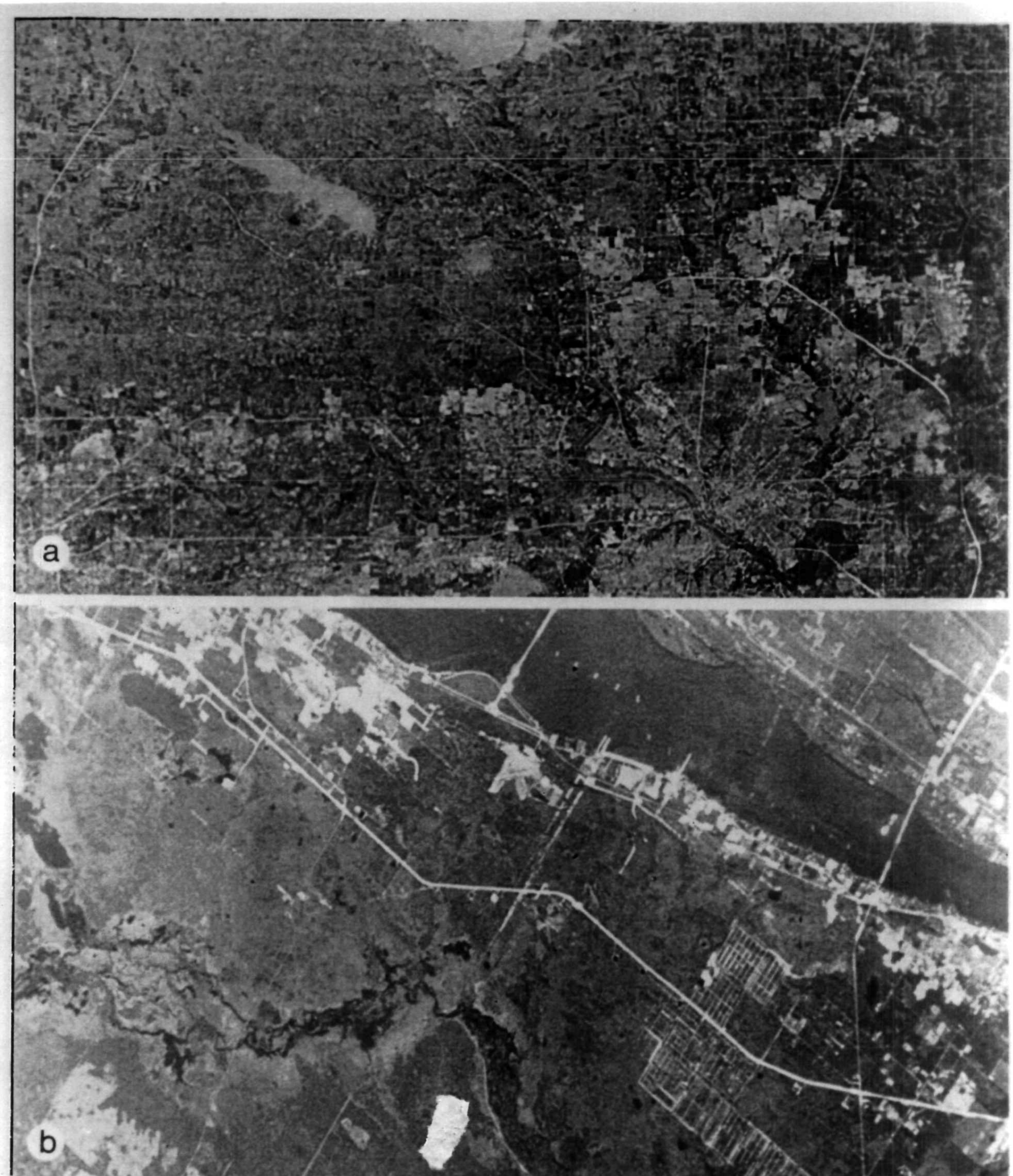


Figure 9. a) This 8X Enlargement from an 80 mm focal length Ektachrome photograph of Dallas-Fort Worth, Texas area has a ground resolution of about 300 feet.

b) This 8X Enlargement from a 250 mm focal length Ektachrome photograph of Titusville and vicinity near Cape Kennedy, Florida has a ground resolution of about 100 feet. This photo was taken from Gemini VII on December 6, 1965.

TABLE 1

DETECTABILITY OF ROADS BY WIDTH ON APOLLO SPACE PHOTOGRAPH			
ROAD TYPE	ROAD WIDTH*	ROAD PLUS SHOULDER WIDTH*	% VISIBILITY
Divided Roadway	46	70	100
Paved Roadway	25	37	80
Bituminous Surface	20	28	65
Metal Surface	19	19	38
Graded and Drained	16	16	18
Bladed Earth	16	16	15

*Average values

TABLE 2

PERCENT OF VISIBLE ROADS ON APOLLO SPACE PHOTOGRAPH TEXAS COUNTIES				
ROAD TYPE	WISE	COLLIN	JOHNSON	HOOD-SOMERVELL
Divided Roadway	100	100	100	NONE
Paved Roadway	80	84	86	69
Bituminous Surface	77	70	65	48
Metal Surface	30	54	49	20
Graded and Drained	17	32	14	11
Bladed Earth	17	0	0	43

TABLE 3

ERROR ANALYSIS OF LINES INCORRECTLY INTERPRETED AS ROADS ON APOLLO 6 COLOR SPACE PHOTOGRAPH DALLAS-FORT WORTH AREA						
	MILES IN COUNTY					
CATEGORY	Collin	Wise	Johnson	Hood-Somervell	Total	%
Streams, Rivers	11.8	25.1	8.2	12.7	57.8	29.3
Field Borders	12.5	11.4	6.9	8.1	38.9	19.7
Pipelines		11.1	11.1	6.2	28.4	14.4
Telephone Cables			3.7	6.2	9.9	5.0
Boonville Oil Field Border		4.7			4.7	2.4
Railroad	7.4		5.6		13.0	6.6
Lakeshore	3.7				3.7	1.9
Erosion Control Waterways	7.2				7.2	3.7
Roads-Trails to Oil Rigs		15.1	.8		15.9	8.1
Unknown	2.5	2.4	5.1	7.6	17.6	8.9
TOTAL MILES	45.1	69.8	41.4	40.8	197.1	100

TABLE 4

ROADS NOT DETECTED AND FALSE ALARM* MILES IDENTIFIED ON APOLLO SPACE PHOTOGRAPH (TEXAS COUNTIES)							
COUNTY	ACTUAL MILES	NOT VISIBLE MILES	%	FALSE ALARM MILES	%	MILES TOTAL ERROR	%
Collin	1080	478	44	45	4	523	48
Wise	984	552	56	70	7	622	63
Johnson	1122	540	48	41	4	581	52
Hood-Somervell	597	371	62	41	7	412	69
Total	3783	1941	51	197	5	2138	57

*False alarm are lines incorrectly interpreted as roads

TABLE 5

COMPARISON OF ROAD DETECTION USING MULTIPLE SPACE PHOTOGRAPHS : COLLIN COUNTY, TEXAS

Position On Photo	Total Miles	Miles Visible	% Visible
I(Upper left)	1184	773	65
II (Upper center)	1188	807	68
III (Upper right)	1157	726	63
Combined Photos	1186	955	80
Original Study	1080	602	56

TABLE 6

LAND USE	BROAD BAND 400-700 nm	BLUE 400-500 nm	GREEN 500-600 nm	RED 600-700 nm	SAMPLE SIZE
WHEAT	700	480	470	290	62
	0.37	0.35	0.36	0.41	
BARE GROUND	530	240	230	250	80
	0.32	0.25	0.30	0.40	
PASTURE	960	370	420	500	92
	0.28	0.35	0.35	0.38	
PAVED ROADS	1740	660	710	910	60
	0.23	0.33	0.33	0.32	
GRAVEL ROADS	1850	740	790	970	53
	0.32	0.39	0.30	0.40	
ROAD DITCHES	870	350	370	400	80
	0.28	0.28	0.35	0.37	
STANDARD GRAY CARD	1350	550	550	550	

Mean reflectivity (plain cells)

Normalized standard deviation (hatched cells) = $\frac{\text{Standard deviation}}{\text{Mean reflectivity}}$

TABLE 7

LAND USE	BROAD BAND 400-700 nm	BLUE 400-500 nm	GREEN 500-600 nm	RED 600-700 nm
WHEAT	2.5-1	1.4-1	1.5-1	3.1-1
	2.6-1	1.5-1	1.7-1	3.3-1
BARE GROUND	3.3-1	2.8-1	3.1-1	3.6-1
	3.5-1	3.1-1	3.4-1	3.9-1
PASTURE	1.8-1	1.8-1	1.7-1	1.8-1
	1.9-1	2.0-1	1.9-1	1.9-1
ROAD DITCHES	2.0-1	1.8-1	1.9-1	2.3-1
	2.1-1	2.1-1	2.1-1	2.4-1

Contrast ratios for paved roads

Contrast ratios for gravel roads

TABLE 8

LAND USE	BROAD BAND 400-700 nm	BLUE 400-500 nm	GREEN 500-600 nm	RED 600-700 nm
WHEAT	1.2-1	0.7-1	0.79-1	1.4-1
BARE GROUND	1.6-1	1.5-1	1.6-1	1.6-1
PASTURE	0.9-1	0.95-1	0.88-1	0.8-1

Contrast ratios for road ditches

TABLE 9

COMPARISON OF TWO SEPARATION TECHNIQUES
FOR ROAD DETECTION IN SPACE PHOTOGRAPHY

METHOD USED*	MILES VISIBLE	% VISIBLE
Color Photo (UK)	326.8	73.3
Red Separations:		
Red Separation (UK)	309.2	69.4
Red Separation (PF)	113.6	29.2
Red Separation - 28 slices in false color (PF)	206.4	49.7
Red Density Slices - B & W, 14 slices (PF)	248.4	55.7
Cyan Separations:		
Cyan (blue-green) Separation (UK)	311.2	69.8
Cyan Separation (PF)	263.2	67.8
Cyan Separation - 18 slices, in false color (PF)	242.8	58.4
Cyan Separations - 3 different exposures (PF)	280.0	63.0
Cyan Density Slices - B & W, 13 slices (PF)	248.0	55.7
Combined Philco-Ford Methods	322.8	72.4
Combined University of Kansas Methods	343.2	77.0
Combined All Methods	355.2	79.7

UK - University of Kansas Separation Techniques, i.e. regular color separation prints, 6x magnification

PF - Philco-Ford Separation Techniques, i.e. transparencies and fine density slices, 10x magnification

* Areas measured vary slightly for different methods due to inconsistency in photographing identical areas.